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Agricultural Memorandum No 975

A Wind-Powered Drainage Pump

I A Barrie

Introduction

A wind powered drainage system with tiled drains running to a large ditch leading to a wind driven pump was installed on a 14 hectare site near Newport, Shropshire during 1982. The wind pump, which stands 4 m high, is based on a Dutch design which has been operating successfully in Holland for many years.

Prior to the drains being installed the water table at the site was seldom far from the surface, even during the summer when the land could be used for rough grazing. The soil profile contains large quantities of peat, varying in thickness between 0.3 and 2 m and overlying a sandy clay sub-soil (Adventurers' Series).

Following completion of the drainage system and pending final field cultivations the reclaimed land will be used to grow maincrop potatoes under irrigation.

This memorandumexamines the climatic aspects of the manufacturer's claims for the pump and appraises the likelihood of success of the system.

Background

Wind pumps for field drainage have been in use for many years and in a previous appraisal Cochrane (1982) considered that for a large site near Market Deeping, Lincolnshire, wind pumps alone would not provide sufficient energy to remove the drainage water.

However, the site on Longford Moor, Newport, differs in two important respects from that at Market Deeping. Of greatest importance is the lower height to which the water has to be raised (the water-head), at 1 m, is considerably less than the 7.5 m Cochrane considered. Additionally, the area of land is much less, 14 ha compared to 40 ha.

At both sites the main ditch may also act as a storage lagoon during times when the flow of water through the drains exceeds the capacity of the wind pump. The ditch at Longford Moor will hold a maximum of 600m^3 of water (equal to only 4.3 mm of rainfall on 14 hectares) but as the ditch fills it will hinder the free flow of the water through the drains (by gravity) and may impede the operation of the wind pump by submerging the inlet valve. Such restrictions would reduce the effective ditch capacity to 200m^3, but the indications are that submergence for limited periods (less than 1-2 days) is acceptable. The tolerance of a crop to a period of waterlogging should also be considered in determining the effective storage capacity.

Pump Performance

1. Pumping Rate

The manufacturers of the pump, Norman Marsh Engineering of Driffield, Yorkshire issue a performance curve with their sales literature. Interpreting the information they provide, the relationship between windspeed and pumping rate can be determined, see fig. 1. The marked effect which the head of water has on the pumping capacity can be seen with the rate increasing up to 3 fold between water heads of 0.5 and 2 m.

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For comparison, at the drainage site at Market Deeping the "best pumping capacity" achieved using a wind-pump supplied by Wakes and Lamb was 0.21 m^3/min (2720 gal/hour). Reference to fig. 1 shows that the Norman Marsh pump can exceed this rate at wind speeds as low as 4.5 m/sec while winds of 10m/sec will give a rate of around 2 m^3/min.

2. Start-up Speed

At the lower end of the curve no start-up speed for the vanes is given, but it can be deduced that with winds of less than 4 m/sec, and against a 1 m head, the volume of water pumped will be minimal. Once started, the inertia of the vanes will ensure that pumping will continue after the wind speed has fallen a little below the initial start-up speed.

A closer examination of fig. 1 shows the critical nature of a start-up speed between 4 and 5 m/sec. An increase in wind speed from 4.5 to 5 m/sec will produce an increase in pumping rate from 0.4 to 1.0 m^3/min. Above 5 m/sec the rate of increase declines. The corresponding curves for 0.5 and 2 m heads of drainage water show similar characteristics but they are not so pronounced.

For an efficient system the pump performance at low wind speeds (< 5m/sec) will be of crucial importance. Typical wind speed frequency distributions for the West Midlands have been produced (HMSO, 1968) and are given in fig. 2. This shows that a speed of 4 m/sec is close to the modal value, during both summer and winter, and that any rise in the starting speed will have a large impact on the number of hours when the pump could be expected to operate. An increase from 4 to 5 m/sec in the start-up speed will reduce the hours available by over 30% although the lower stopping speed of the vanes may reduce this value a little.

3. Monthly Potential Pumping Rates

With knowledge of the average windspeed distribution (fig. 2) and the corresponding pumping rates for each speed (fig. 1) it is straightforward to construct the theoretical volume of water value which could be pumped in a typical winter month if the supply of water to be drained was unrestricted.

Table 1 Monthly Potential Pumping Rates

windspeed m/sec	average hrs* per month	pumping / capacity m^3/min	potential capacity of pump (m^3/month)
0.0-4.0	382	0.0	-
4.5	61	0.4	85
5.0	53	1.1	3498
5.5	45	1.2	3240
6.0	39	1.3	3042
6.5	32	1.4	2688
7.0	25	1.5	2250
7.5	20	1.65	1980
8.0	16	1.8	1728
8.5	12	1.85	1332
9.0	9	1.95	1053
9.5	7	2.0	840
10.0	6	2.05	738
>10.0	13	2.1	1638
	720		24112 m^3

* based on winds recorded at Shawbury, during 1971-80, at 10 m.
/ based on manufacturer's data for a 1 m head of water.

In practise it is most unlikely that the supply of drainage water will be such that the pump will work for every day in any given month, but the above values do give an estimate of the performance of the pump over a longer time period.

On a 14 hectare site a monthly total of 24000 m^3 of water is equivalent to 170 mm of rainfall; much more than could reasonably be expected to fall. With an average monthly rainfall of around 55 mm, a fall of 170 mm could be expected on average only once in every 10 years for a particular winter month.

Regional Variability

On a regional scale, maps have been produced which show the annual percentage of time for which windspeeds of certain limits may be exceeded (Caton, 1976). Two of these have been reproduced in figs. 3 and 4 to give the 50 and 75 percentiles. The 50 percentile line is important because the windspeed corresponding to this value is near to the start-up speed for the pump.

This agrees well with table 1 in indicating that windspeeds on an annual basis will be too low to operate the pump for just over 50% of the time.

Exposure and Surface Roughness

The height of the vanes above ground level and the nature of the surrounding countryside are important factors because windspeed usually increases logarithmically with height, and also with reduced surface frictional drag. If there are many hedges or buildings in the immediate vicinity of the pump then frictional effects will reduce the windspeed at vane height. To alleviate such a loss, a taller mast, say 7 m rather than 4 m, would be worth considering.

Fig. 5 illustrates the inter-dependence between surface roughness and the height of exposure through the application of the equation which defines the logarithmic increase of windspeed with increasing height.

$$\frac{Uh}{U10} = \log_e \left(\frac{h}{Zo}\right) \Big/ \log_e \left(\frac{10}{Zo}\right)$$

Where Uh is the windspeed at height h

U10 " " " " 10 m

Zo is the roughness length and may be taken as 1/10 of the obstruction height.

Typical values of Zo give

Zo = 0.02 for a flat open field
= 0.1 for rough land or a cropped surface
= 0.2 for land with hedges, trees or buildings.

From fig. 5 it can be seen that for a surface with Zo = 0.02 the increase in windspeed (expressed in terms of a fraction of the 10 m wind) gained by using a 7 m rather than 4 m mast, would be from 0.86 to 0.94 (or 9%), while the increase over land with Zo = 0.2 is from 0.76 to 0.91 (or 20%).

Clearly, the extra investment would prove worthwhile if the exposure of the mast was in any doubt, especially in light of the critical nature of the graph in fig. 1 showing that the start-up speed needs to be exceeded by at least 1 m/s to gain the greatest benefit.

Rainfall, Soil Moisture and Design Features

The tile drain design value for the Longford Moor site is for a 9 mm rainfall in a 24 hour period. This amount of rain falling on a 14 hectare site will produce 1260 m^3 of water (277,200 gallons). In practice some of the water will be lost through evaporation and/or in restoring a soil moisture deficit (SMD) if one exists at the time. To pump 1260 m^3 of water against a 1 m head in 24 hours, a steady windspeed of just under 5 m/s (~9 knots) would be necessary. A windspeed of 5 m/s is above the median value for this area and as there is no evidence linking high windspeeds to heavy rainfall (Zobel, 1965) then it must be expected that the main ditch will have to provide temporary storage fairly frequently.

A site in the Newport area could be expected to have a 24 hour rainfall of 25 mm or more twice during each year on average. During the winter half year (Oct-Mar) a fall of 35 mm or more is likely once in five years on average. Due to the more thundery nature of our summer weather the heaviest and more frequent short period (24 hours or less) rainfalls are to be expected at this time. With drains laid at a depth of 1 m an SMD of 50-100 mm during the summer would be common, assuming that no irrigated water had been applied. This will act as additional storage for summer storms (once in five year return period value of 40 mm in 24 hours). If, however, no SMD was available and given that light winds are more common during the summer then the twice in one year value of 25 mm would overfill the main ditch and lead to flooding. At such times the optional tractor drive with a pumping rate of 2.3 m^3/min (500 gallons/min) would be needed.

Since the installation during October 1982 there has not been more than 65 mm in any month and the winter rainfall was only 84% of average. A severe test of the pump is therefore still awaited.

If the performance curves produced by the company are even a little optimistic in the 4 to 5 m/s range then the pump will fall short of its expected performance because of the relatively low frequency of higher windspeeds.

Summer waterlogging of the soil may prove to be a problem especially if a strict irrigation plan is followed to restrict the SMD to say 25 mm. If this proves to be the case then a less demanding plan of say 25 mm irrigation at a 50 mm SMD would give the extra storage of rainfall following a storm.

Summary

The wind powered drainage pump manufactured and sold by the company is a custom-built field drainage pump designed to operate at low water heads. Their literature suggests that it has a start-up speed of around 4 m/s, and at speeds above 5 m/s the pump operates at a much increased rate (against a 1 m head). The maintenance requirements are simple but essential if the initial rapid response to wind between 4 and 5 m/s is to be exceeded.

In the absence of natural drainage there will be times when the pump alone will be unable to cope, due to either heavy rainfall and/or low windspeeds. The optional tractor drive would then be needed to clear the drainage water.

Addendum

The heavy rainfall during April, amounting to over 100 mm in the area, combined with generally light winds would have resulted in flooding if a 50 hp tractor had not been used to drive the pump on most days during the first two weeks. The crop is currently being planted so extra efforts were made to keep the water table as low as possible. The farmer is pleased with the results obtained.

Any comments or suggestions on this memorandum should be referred to the author.

Met. Unit
MAFF/ADAS
"Woodthorne"
Wolverhampton

27 May 1983

References

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Cochrane, J 1982 Windmills for pumped drainage. Agricultural Memo.No. 938.

HMSO 1968 Tables of Surface Wind Speed and Direction over the United Kingdom. Met. O. 792

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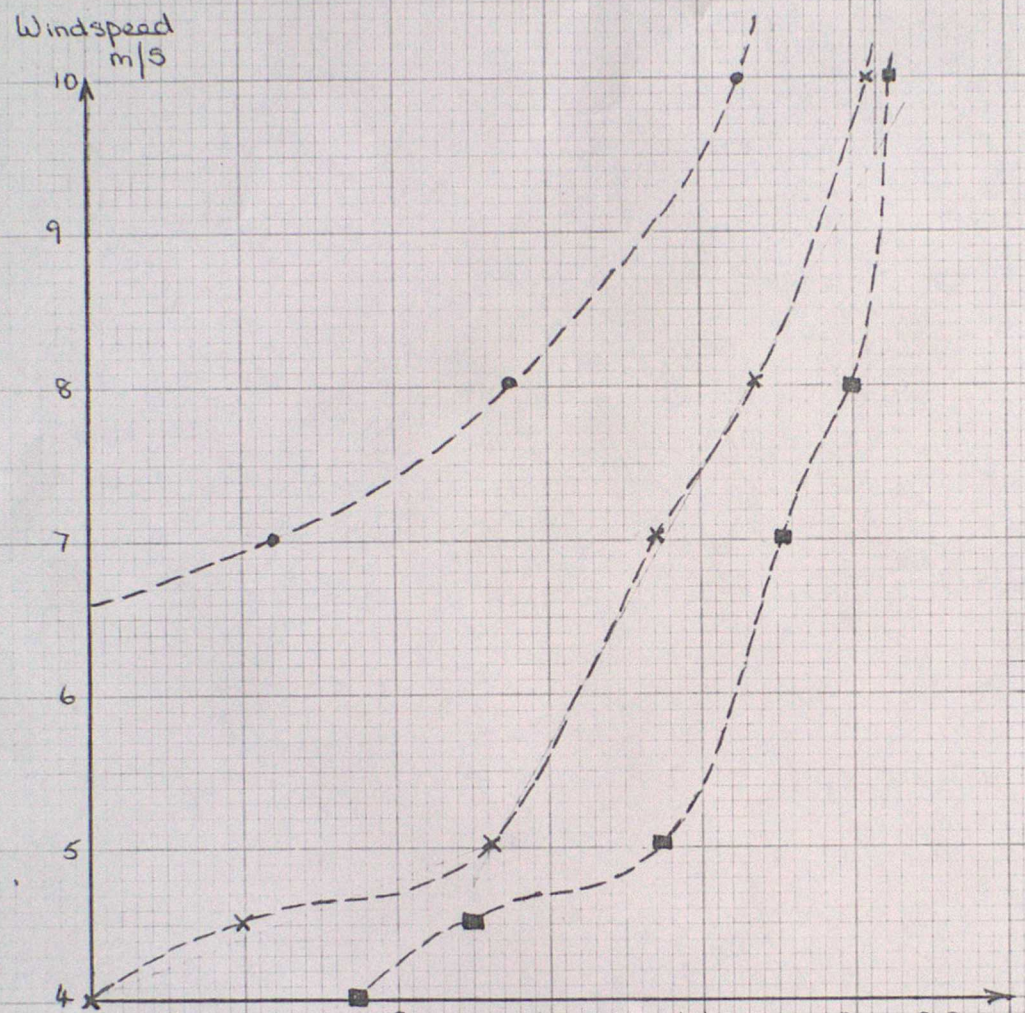
Acknowledgement

The advice given by Mr F A J Sparkes and Mr T Preece, Land Drainage, is appreciated. Thanks are due to Mrs K Hollyhead for preparing the diagrams.

THE RELATIONSHIP BETWEEN WINDSPEED AND PUMPING RATE
(manufacturers data)

FIG 1.



Head of water

- ● 2m
- × 1m
- ■ 0.5m

conversions

1·0 m³/min = 1000 l/min
= 220 gal/min
= 13 200 gal/hour

10 m/s = 22·4 mph
= 19·5 knots

FIG 2.

Seasonal Windspeed Distributions

Edgebaston 1950-59.

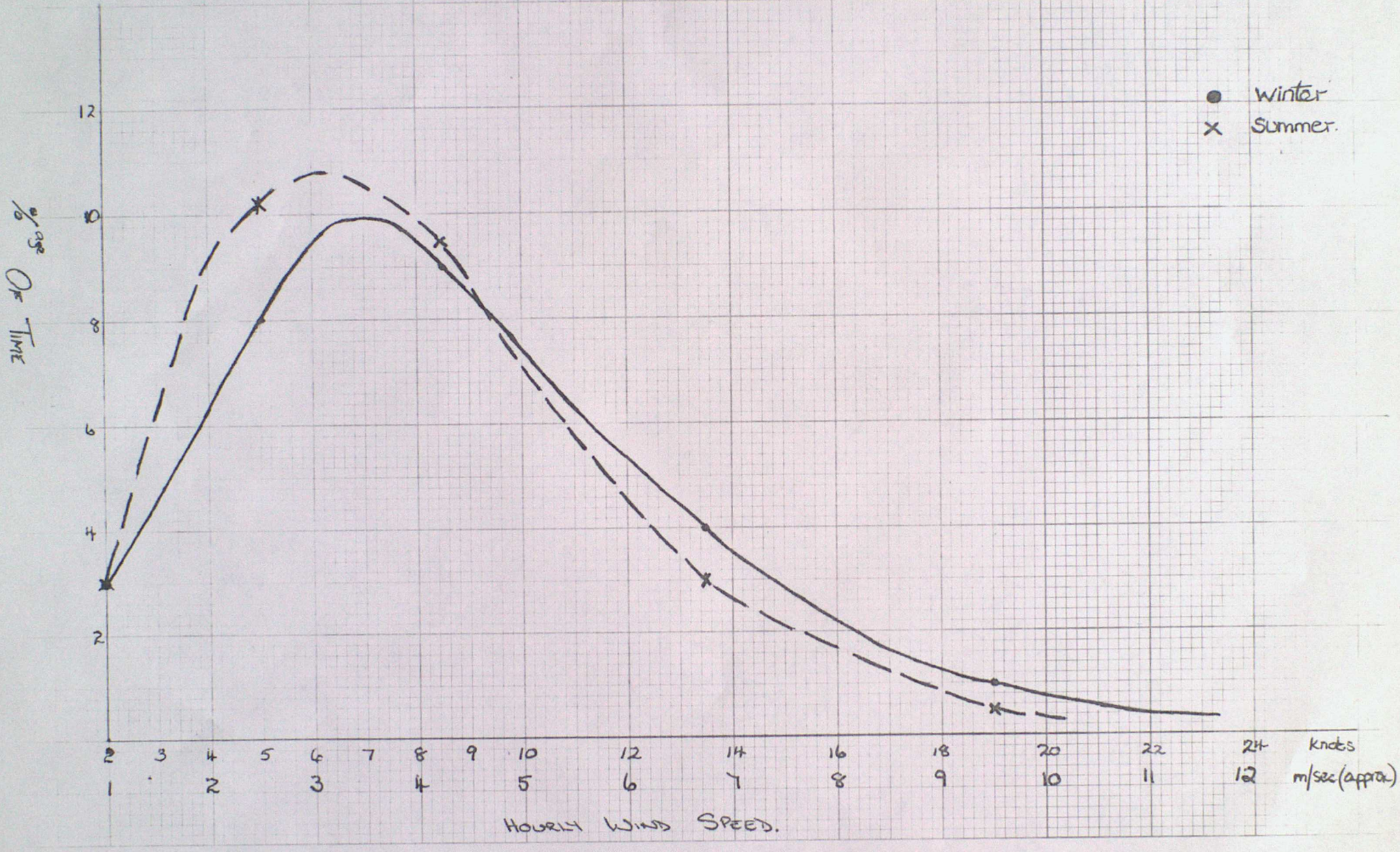


Fig. 3

Hourly mean speed (m/s) exceeded for 50% of the time during the years 1965-73. Valid for a height of 10 m above open, level terrain and for altitudes between 0 and 70 m above sea level.
Local topography may significantly alter these average values.

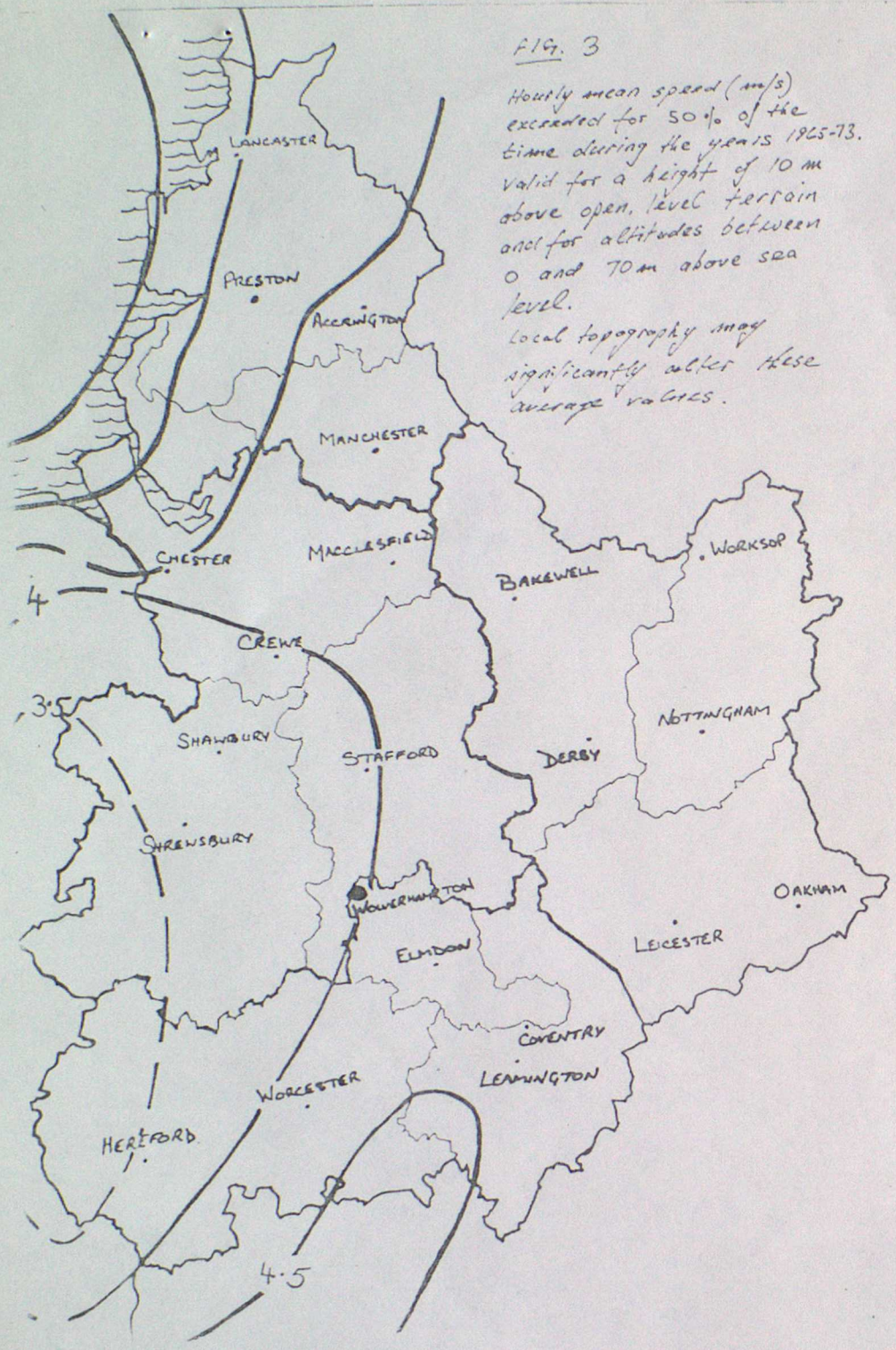
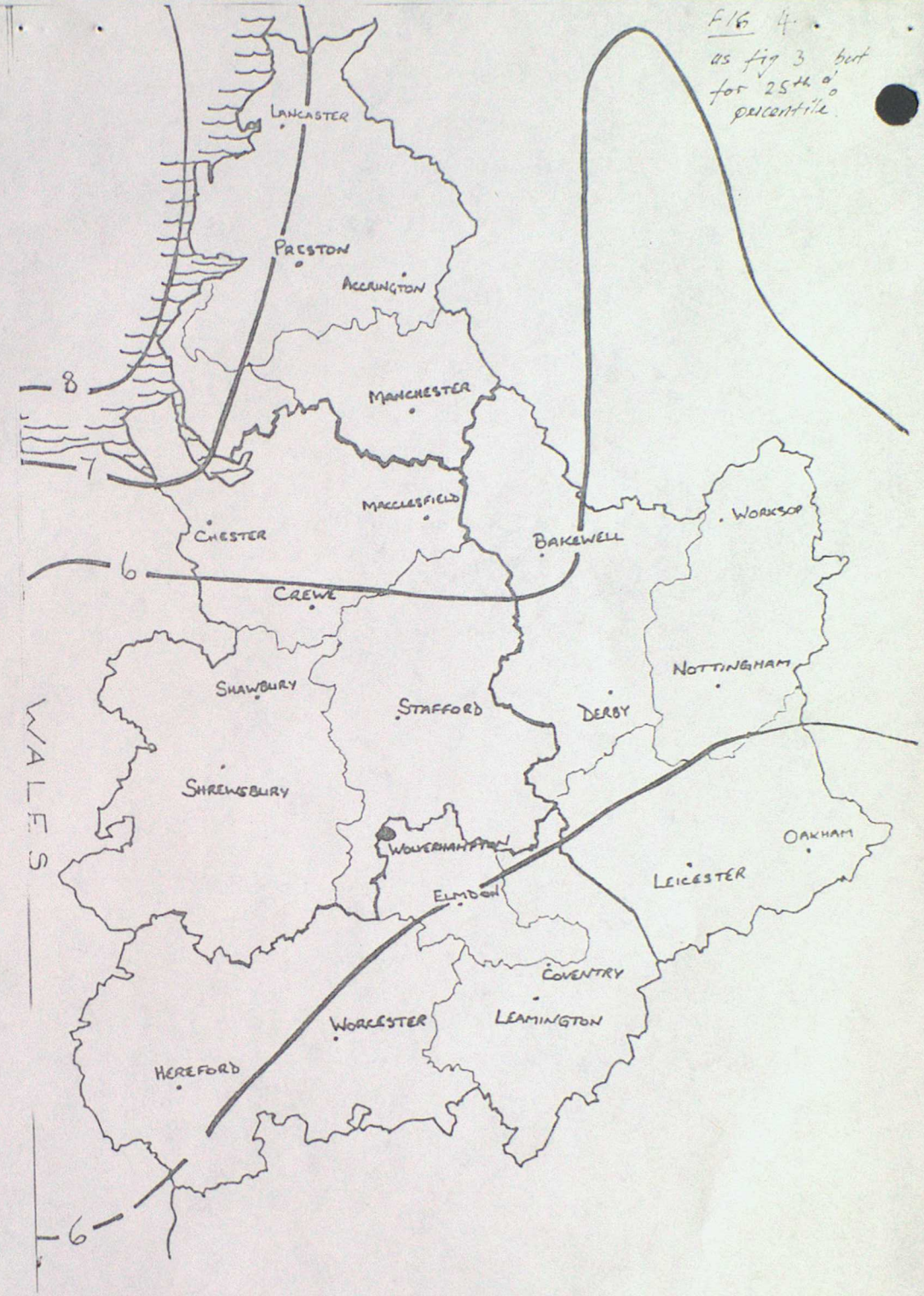


Fig 4

as fig 3 but for 25th percentile



The Effect Of Surface Roughness On Windspeed

FIG 5